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Introduction to plastics recycling

Introduction:

- The UK currently recycles or recovers approximately 19% of all plastic consumed. This is set to increase to over 25% by 2010.
- Generally, plastics are made from crude oil. Recycling of plastics therefore helps to conserve this natural resource.

Types of plastics according to processing:

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Term	Meaning
Virgin grade	A material that has not yet been processed
Recyclate	A material that has already been processed
Reclaim	A material reclaimed from the waste stream for recycling A material is reclaimable when both a treatment technology and a market for the resulting new material are available

- **Reuse:** Using of product again with small change in outer shape (as cleaning) to be new again.
 - Reuse is not widely practiced in relation to plastic packaging - plastic products in general tend to be discarded after first use. However, there are examples of reuse in the marketplace. For example, a number of detergent manufacturers market refill sachets for bottled washing liquids and fabric softeners. Consumers can refill and hence reuse their plastic bottles at home.
- **Mechanical recycling (physical recycling):** The plastic is ground down and then reprocessed to produce a new component that may or may not be the same as its original use.
 - Mechanical recycling is the most widely practised of these methods.
- **Feedstock recycling (chemical recycling):** the polymer is turned back into its oil/hydrocarbon component for use as raw materials for new polymer production.
- **Energy recovery:** the materials are incinerated to recover their inherent energy.

- No manufacturer wishing to stay in business can recycle materials if it is not profitable to do so. Recycled plastics are used in the same market in which they originated.

Common polymers:

Polyethylene

Polyamide 6

Terephthalate

Melamine-formaldehyde resin

Polypropylene

Polyamide 55

Polyvinyl chloride

Phenolic resin

Polystyrene

Polyethylene

Epoxy resin

Unsaturated Polyester

- LD: Low density

HD: High density

Table 2.3 Common thermoplastics and their applications		
Thermoplastic Polymer	Applications	Lifetime range
HDPE	Packaging, pipes, tanks, bottles, crates	Packaging: 2 years Pipes: 30 years
LDPE	Packaging, grocery bags, toys, lids	Packaging: 2 years
LLDPE	Packaging	2 years
PP	Caps, yoghurt pots, suitcases, tubes, buckets, rugs, battery casings, ropes	Packaging: 2 years Battery casings: 10 years
Polystyrene (PS)	Mass produced transparent articles, yoghurt pots, fast food foamed packaging, cassettes	Packaging: 5 years Cassettes: 10 years
Polyamide* (PA)	Bearings, gears, bolts, skate wheels, fishing lines, carpets, clothing	10 years
Polyethylene terephthalate (PET)	Transparent carbonated drink bottles	5 years
Polyvinyl chloride (PVC)	Food packaging, shoes, flooring	5 years
* Also known as Nylon		

Table 2.6 Common thermoset materials		
Thermoset Polymer	Application	Lifetime range
Epoxy	Adhesives, electrical insulation	10 years +
Melamine-formaldehyde resin	Heat resistant laminate surfaces, i.e., kitchen worktops	10 years +
Phenolic	Heat resistant handles for pans, irons, toasters	10 years +
Polyurethane (PU)	Rigid or flexible foams for upholstery and insulation	10 years +
Unsaturated polyesters	Partitions, toaster sides, satellite dishes	10 years +

Additives:

- Plastics are made up of polymers and other materials that are added to give the polymer increased functionality.
- There are many additives commercially available that can be mixed with polymers. For example, glass or carbon fibre reinforcement gives them increased strength. Flame-retardants can be added for flame resistance. Plastics can be coloured with pigments for aesthetic or technical purposes, or they can be made more heat and light resistant by the use of stabilizer additives.
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Table 2.7 Common additives for plastics	
Additive	Purpose
Glass fibre	Increased strength and stiffness
Calcium carbonate	Filler used for cost reduction: much cheaper than polymer
Flame retardant	Increased fire resistance
Light stabilisers	Increased resistance to degradation due to light exposure
Heat stabilisers	Increased resistance to degradation from elevated temperature exposure
Pigments	Give colour, improve aesthetic properties
Foaming agents	Lightness and stiffness
Mould release agents	Processing aids
Anti-static additives	E.g., prevent dust build up on consumer items
Plasticisers	Reduce viscosity, aid processing

- Not all recyclates are black but depending on input colours especially for transparent colours.
- Except for food-contact and medical polymers, percentage of recyclates can be introduced to virgin products to reduce costs.

Recyclates outlines:

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Table 2.8 Examples of outlets for recyclates	
Thermoplastic Polymer	Recyclate Applications
HDPE	Non-food bottles
LDPE	Refuse bags, carrier bags
PVC	Non-food bottles, cable conduits, ducts and sewage pipes, multi-layer PVC flooring
PP	Battery casings, bumpers, garden furniture
PS	Audio and video cassettes, compact disc trays, coat hangers
PA	Fibre for carpets
PET	Non-food bottles, fibres for clothing, sleeping bags
Mixed Plastic Waste (MPW)	Wood replacement products such as pallets and fencing

TP processing properties:

- Polymers combine both viscous and elastic properties i.e. viscoelastic (more viscous than most liquid and more elastic than most solids).
- Elasticity and viscosity are important during processing of TP; on heating viscosity affects
- TP flows as liquid only; temperature is more than melting point and discolouration occurs.
- Homogeneous: a material with the same properties at all points.
- A phase: a physically homogeneous, mechanically separable portion. Think of a phase as a distinct identifiable region.
- Heterogeneous: a material consisting of two or more phases.

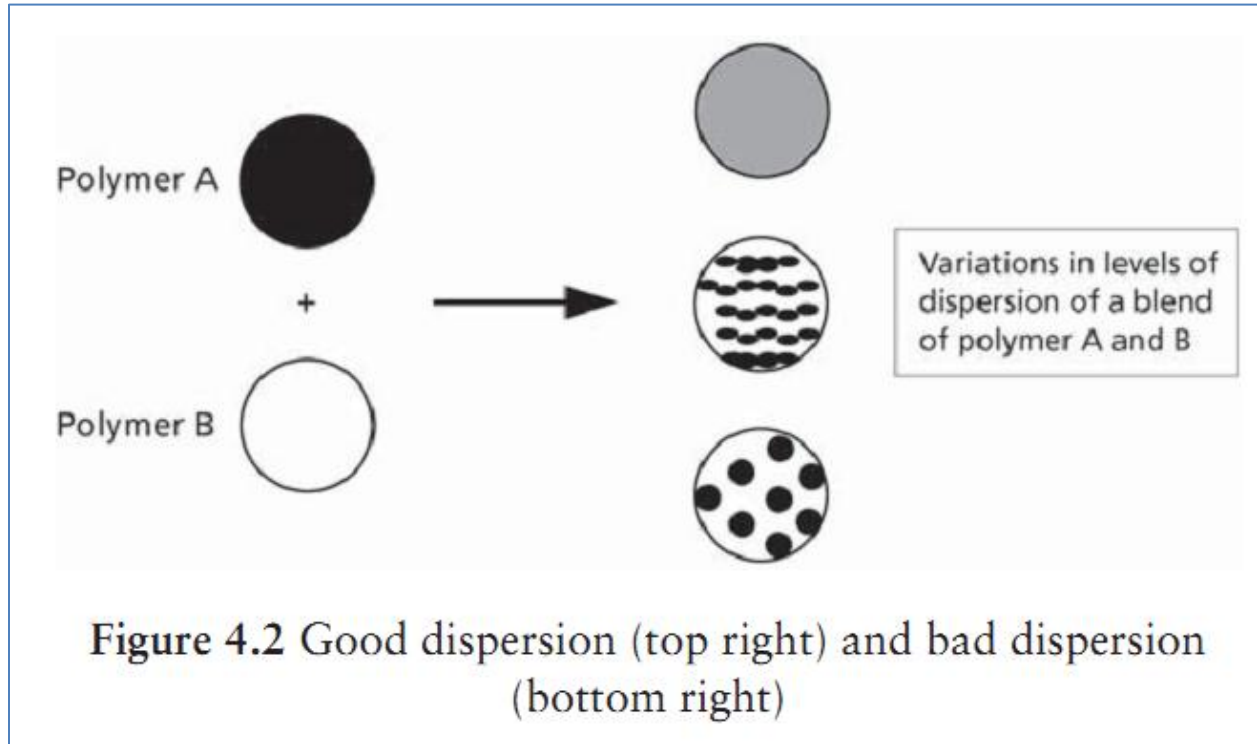
- ## Sorting of plastics:

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Polymer	PS	PA	PC	PVC	PP	LDPE	HDPE	PET
Polystyrene	Y							
Polyamide	N	Y						
Polycarbonate	N	N	Y					
Polyvinyl chloride	N	N	N	Y				
Polypropylene	N	N	N	N	Y			
Low-density PE	N	N	N	N	N	Y		
High-density PE	N	N	N	N	N	Y	Y	
Polyethylene terephthalate	N	N	N	N	N	N	N	Y

Y = miscible, N = immiscible

$Y = miscible, N = immiscible$



- The act of processing causes degradation of the material as a result of heat and shear.
- Mechanical actions such as grinding also exert shearing components.
- problems associated with the processing of mixed plastics:
 - 1- Plastics have different melting points and different temperatures for the onset of thermal degradation.
 - 2- The immiscibility of plastics with each other, leads to deterioration in mechanical performance.
 - 3- Good dispersion and homogeneity are required.

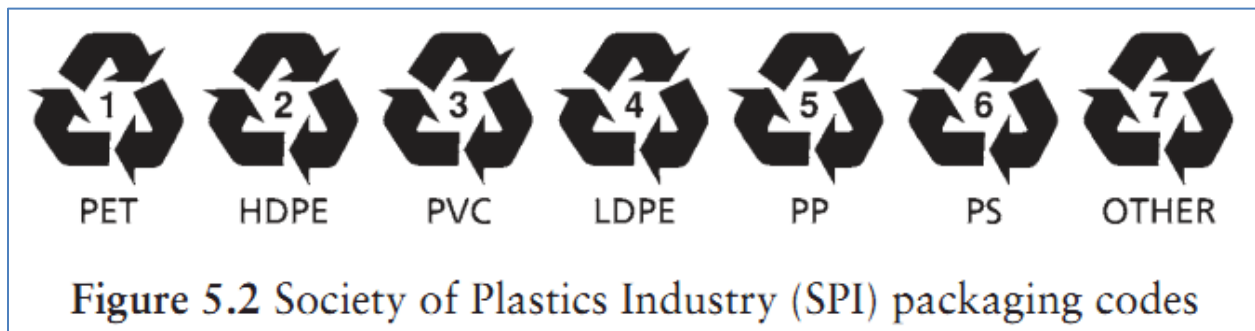
Reprocessing of TP recyclates:

Table 5.1 Types of mechanical recycling	
Primary Recycling	'In-house' reprocessing of production waste
Secondary Recycling	Mechanical recycling of single or mixed plastic materials from external sources

- The characteristics of plastics can change depending on the exposure to thermal, mechanical (shear), oxidative and photochemical degradation processes. The characteristics of the recyclate may be quite different from those of the original virgin plastic.
- Contaminants reduce the mechanical properties of components.
- Contaminants are removed using filters and metal filters (screened to be changed).
- The ideal is streams of single, clean and homogeneous recyclates, which present little technical effort for recycling.

Recycling symbols:

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- 1- polyethylene terephthalate
 - 2- High density polyethylene
 - 3- Polyvinyl chloride
 - 4- Low density polyethylene
 - 5- Polypropylene
 - 6- Polystyrene
 - 7- Other TP
- In UK:

Table 5.2 Mixed plastic fraction of household wastes	
Plastic	Fraction (approximately %)
Polyethylene	55
Polypropylene	15
Polyvinyl chloride	11
Polystyrene	9
Expanded polystyrene (foamed materials such as fast food packaging)	3
Remainder (various)	7

Size reduction:

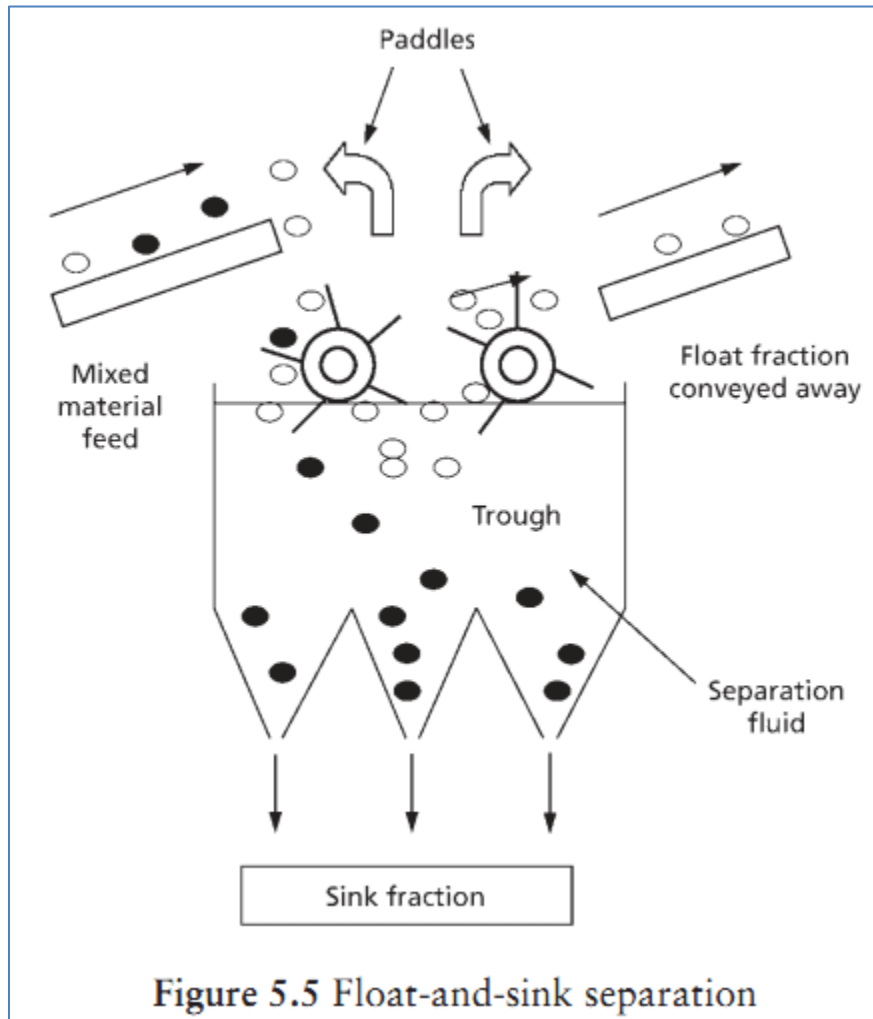
- Size reduction is necessary, because the material particles must be a suitable size for further processing using a shredder to produce large particles of about 25-50 mm and these materials can then be flaked.
- Rotary cutters are most commonly employed for the latter, as they can be used for comminuting (breaking down the size of) virtually any plastic.
- The rotary cutter is a fairly simple device consisting of the rotor and rotating knives, stationary (stator) knives, the grinding chamber and the screen.
- As the plastic moves between the stationary and rotating blades it is cut down to size. This size is determined by the mesh size of the screen, a common size is around 5 mm × 5 mm.
- A rotary cutter must be able to dissipate the heat generated from the shearing action of the blades. This can be done with an air extractor, which also aids in moving regrind material out of the chamber.
- Because contaminants may get into the system and because of the variable hardness and variety of plastics, the knives are mounted to attain the best cutting action possible. It is important as a design feature that the knives can be rapidly re-set, replaced or removed for resharpener as they are likely to undergo considerable wear.

Washing:

- Washing is required to remove any dirt and residues adhering to the waste plastic; it increases the purity of the plastics and in some cases improves the efficiency of other processes such as sorting.
- The contaminants must adhere more strongly to the cleaning medium than the plastic to allow for removal.
- Washing also removes labels and water soluble glue residues.
- Once the materials are washed they then need to be dried either mechanically using gravity and a conveyor to allow any liquid to drain away or thermally using hot air to dry the plastic flakes.

Sorting:

- Using path full of water
- technique involves a floating fraction and a sinking fraction and this is benefit as in figure:



- Further technique for separating generic material types is infra-red (IR) sorting. On exposure to IR light, the polymer molecules emit light energy, this can be detected and the spectral distribution that is produced is characteristic for each material type.
- There are other techniques to separate plastics by colour, electrostatic charges and surface properties. The choice of sorting technique needs to take into account the likely composition of the plastic waste and utilize the best and most economically available technology to attain end products of suitable purity for processing.

Agglomeration

- Agglomeration is a process stage to be carried out after the material is sorted into a fairly homogeneous stream. The aim of the agglomeration is to increase the bulk density of the waste, which is necessary to ensure good feeding for some plastication units.
- Agglomeration can be differentiated from processing as here the aim is simply to bond the flakes together at their surfaces and therefore only the surfaces of the plastics are affected. Pressing or fusion are used for this, with the material being thermally stressed on the surface particles only for a relatively short time. is necessary to ensure good feeding for some plastication units.



Figure 5.6 Film waste before and after agglomeration

Processes:

1- Extrusion:

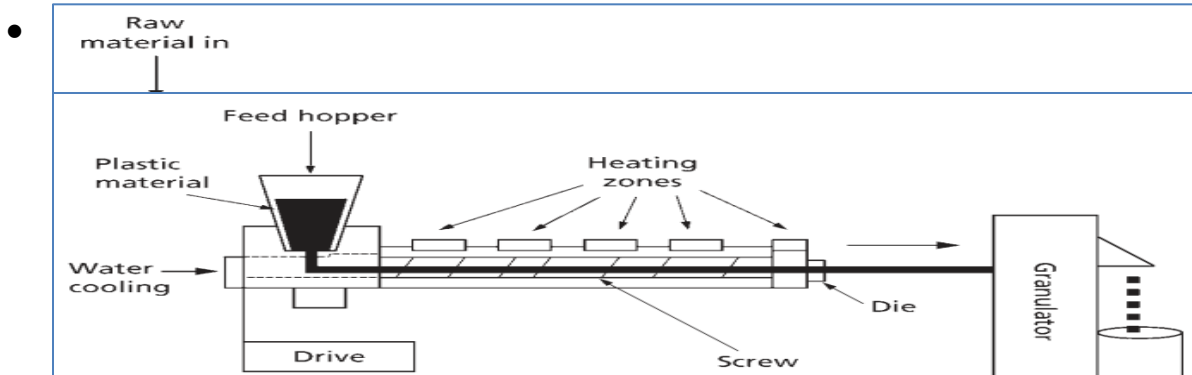


Figure 6.4 Schematic of an extruder

- Extrusion is a continuous process for the production of components such as pipes or sheets. It can also be used to produce compounds, which are mixtures of polymers or plastics and further additives.

- Parts:

1- The Extruder

- a-** Single: the single-screw extruder has a single Archimedian screw that rotates in a heated metal barrel.

A breaker plate is used to take the rotation out of the melt. Without a breaker plate, the material would spiral out of the die in line with the movement of the screw. It also helps to build up pressure in the melt.

- b-** Double:

A twin-screw extruder can have either counter-rotating or co-rotating screws. Co-rotating twin-screw extruders are used mainly for compounding. Counter-rotating screws are generally used in the processing of heat sensitive materials, such as polyvinylchloride (PVC) pipes and sheets. because they allow greater temperature control.

Because of the combination of feeding and screw action, twin-screw extruders can produce compounds with very low levels of polymers, in some cases less than 20%. The single-screw extruder cannot cope with such high levels of non-polymeric materials.

2- The Die

- 3- **An External Cooling Unit:** This is required to cool the molten material and in its simplest form may be a bath either filled with or spraying water. Rollers are used to help feed the material to the cutting device.

- 4- **A Cutting Device:** This is required to cut the extrudate to an appropriate size.

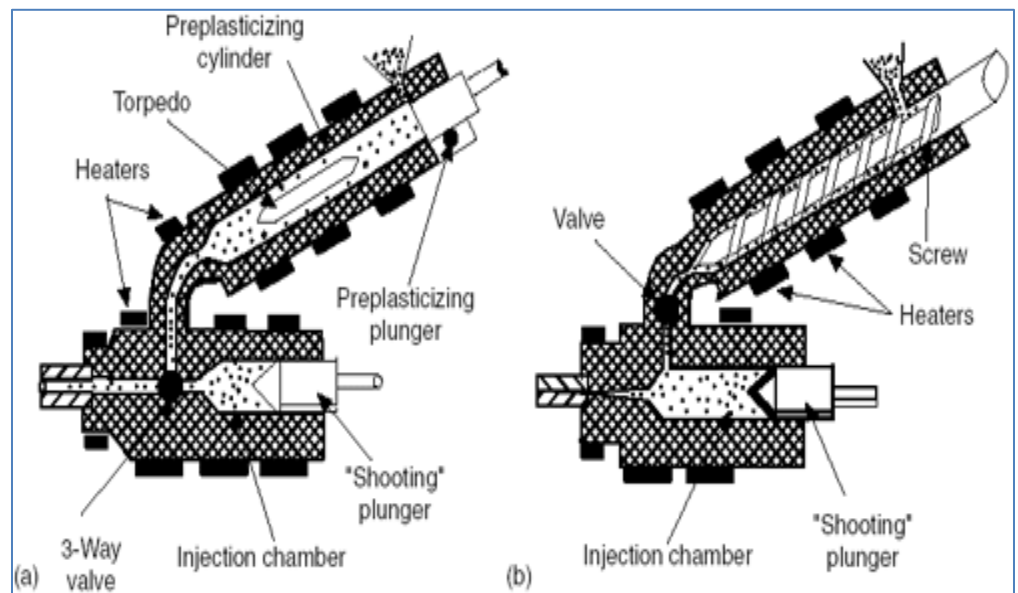
2- Injection moulding:

- It lends itself to high volume production of both complex and precision parts with a variety of uses. It is a highly versatile process that is as successful and economic for both small and large components from an automotive bumper to intricate wristwatch parts.
- An injection moulding machine consists of an injection unit and a mould clamping unit.

- The injection unit must convey, plasticate, mix and homogenise the melt. It must also be able to inject a fixed weight into the mould. This is called the shot weight and will vary depending on the shape and size of the component to be moulded.
- The clamping unit is responsible for opening and closing the mould as well as part ejection after moulding. The clamping mechanism applies a clamping force on the mould, to hold it together whilst the plastic material is injected.
- A simple description of an injection moulding cycle is:
The mould closes, Material is injected, the material cools in the mould, the injection unit meters the next shot, the mould opens and the part is ejected.
- Moulding machine uses a screw to feed and plasticate the melt. There are however, a number of design differences between the two. An injection screw must withstand both higher pressures and intermittent stop-start use. It must be able to inject as well as move back to prepare the next weight of shot.
- For normal cases wastes of runners and sprue are present.

3- Co-injection moulding:

- It is adding core material to original material during injection moulding.



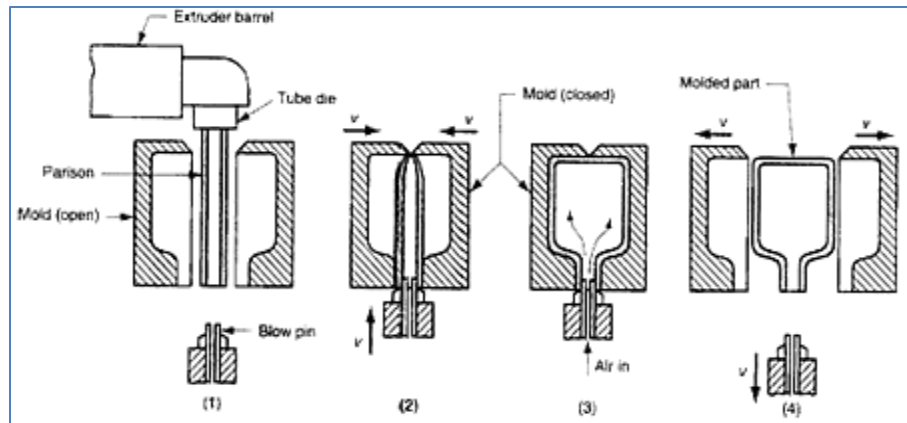
4- Blow moulding:

- It is used to produce range of hollow articles from injection or extrusion.

- It has several types:

- Process for extrusion blow moulding:

- The parison will continue to extrude until it reaches the base of the mould. At this point the mould will close and the parison will be cut above the mould with a hot knife.
- The mould is now moved away from the parison, taking the cut off slice of parison closed in the mould with it.
- The next parison continues to extrude. The inflation of the parison can now commence.
- A blow pin comes down into the top of the mould and blows air in to inflate the hot parison against the sides of the mould (Figure 6.13).
- The mould is cooled with water: this aids heat removal to help solidify the newly formed article.



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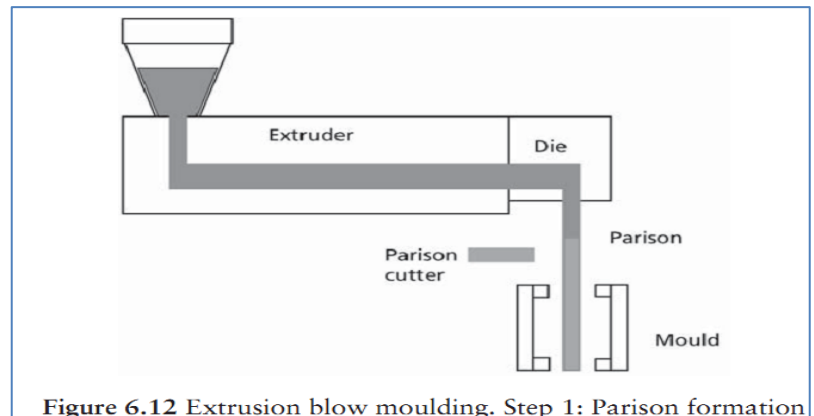


Figure 6.12 Extrusion blow moulding. Step 1: Parison formation

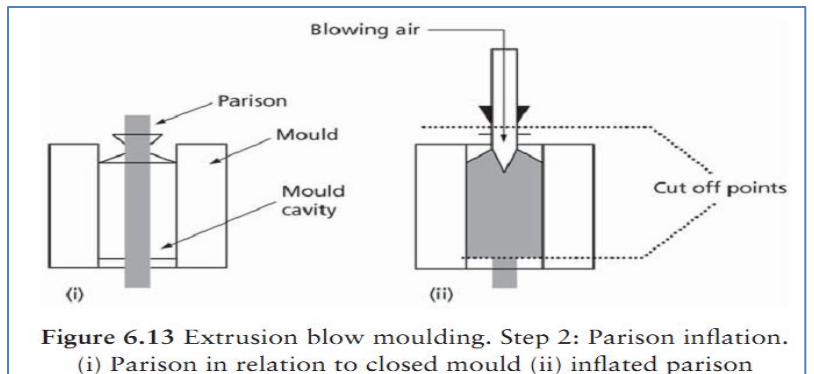


Figure 6.13 Extrusion blow moulding. Step 2: Parison inflation.
(i) Parison in relation to closed mould (ii) inflated parison

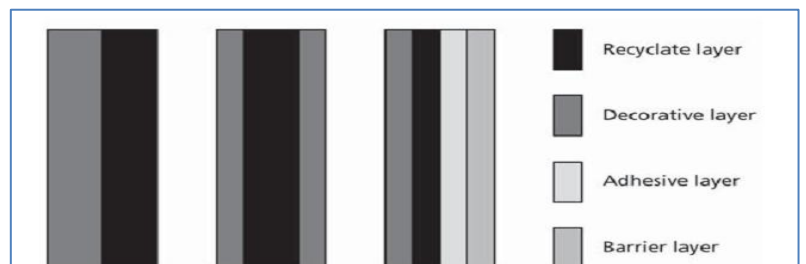
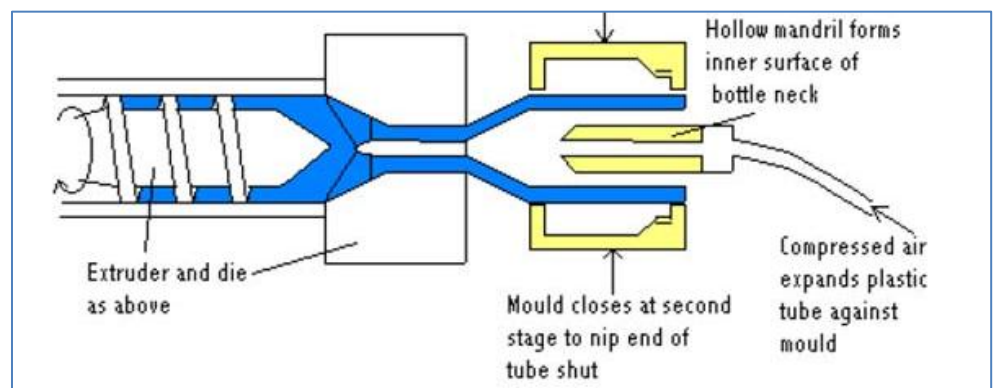


Figure 6.14 Examples of multi-layer structures for blow mouldings

- 6- The blow pin is removed and the tool opens to eject the part.
- The mould can then return to collect the next parison and start a new moulding cycle. The top scrap is termed 'neck flash' and is removed by a cutting device incorporated into the blowing pin, which matches the cutting region on the mould. Providing that the scrap from both the top and bottom is kept clean, it can be reground and returned to the production process. 100% reground can be reused if required.
- **Generally, however, it would be blended with virgin material. Recyclates coming from other waste streams are more difficult to process due to the problems of contamination.**

5- Film blow moulding:

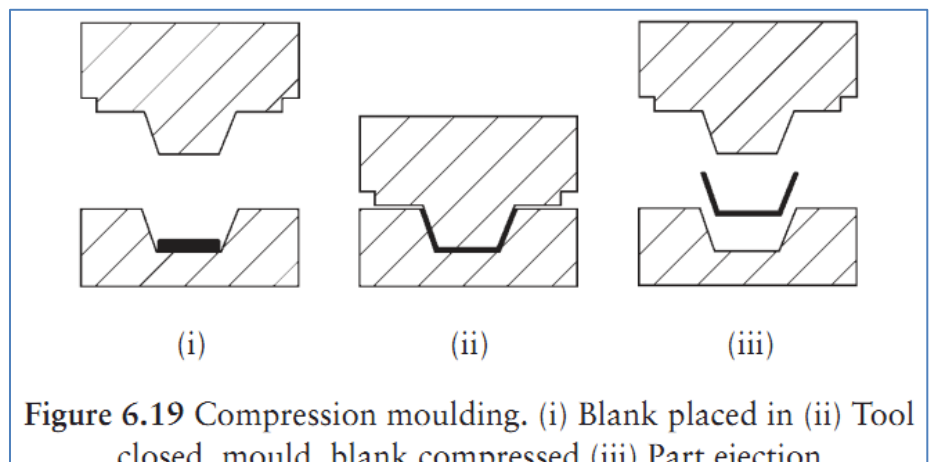
- Generally film blowing is limited to polyolefin materials, the majority of usage being of LDPE, LLDPE and HDPE.



6- Compression moulding:

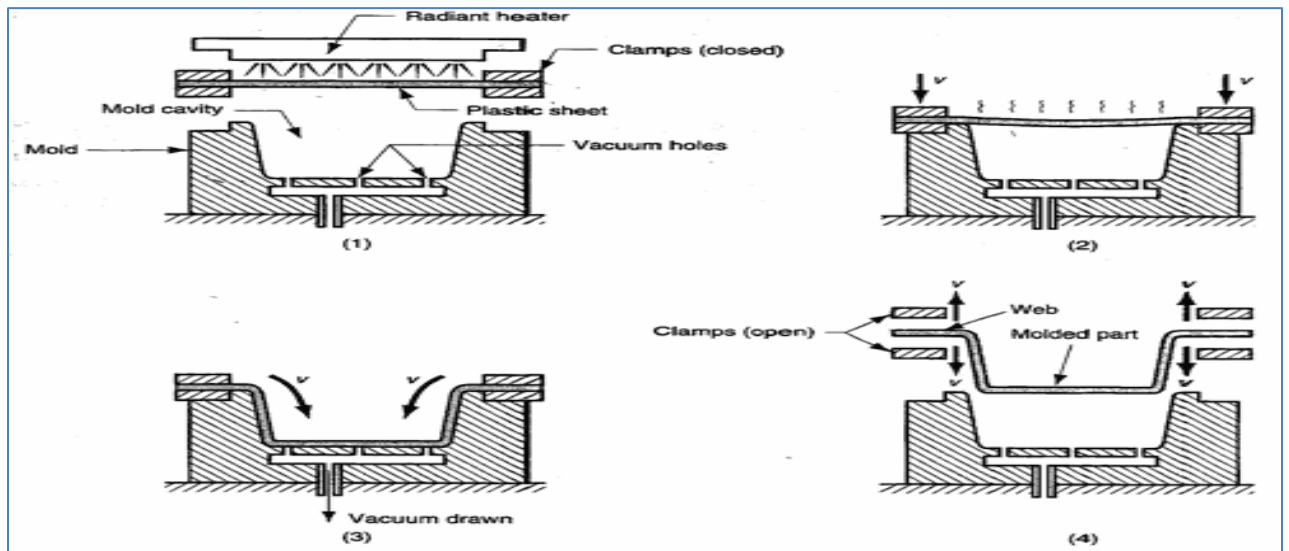
- For thermoplastic and thermoset products.
- Process:

- 1- The moulding compound is loaded.
- 2- The mould is closed.
- 3- The compression force and the heat of the mould cause flow.
- 4- The mould opens.
- 5- The part is ejected.



- Compression moulding of mixed plastics is possible.

7- Thermoforming:



- Like compression moulding, thermoforming uses sheet rather than granules. In this process the sheets are clamped onto a frame and then heated to soften, but not melt, the plastic. A mould is then brought into contact with the sheet whilst a vacuum is applied. This draws the sheet onto the surface of the mould and forms the moulding.
- The moulding must be trimmed to remove the excess sheet material.
- This scrap can be returned to the sheet supplier to be used in the production of new sheet.
- Polystyrene foam and polyethylene are commonly used in thermoforming. Both of these materials are used to produce packaging, such as fast-food boxes, pots and dishes. Drink dispenser cups are also commonly produced by thermoforming.

Processes comparison:

Table 6.1 Comparison of processes					
Process	Complexity of parts	Forming action	Mould	Plastic types	Tolerance to contaminants
Extrusion	Fairly simple profiles	Extrusion	None	Single	Low
Injection moulding	Complex	Injection	Closed	Single	Low
Co-injection moulding	Complex	Injection	Closed	Single layers	Low
Compression moulding	Simple	Compression	Closed	Single	Medium
Extrusion blow moulding	Complex	Inflation	Closed	Single	Very low
Multi-layer extrusion blow moulding	Complex	Inflation	Closed	Single layers	Very low
Injection blow moulding	Simple	Inflation	Closed	Single	Very low
Film blowing	Simple	Inflation	None	Single	Very low
Intrusion moulding	Simple	Compression	Open	Mixed	High
Sinter moulding	Simple	Compression	Open	Mixed	Very high
Transfer moulding	Simple	Compression	Closed	Mixed	High

Additives to recyclates:

- Problems associated with plastics recycling are:
 - 1- The degradation of the plastics as a result of both processing and service life.
 - 2- The difficulties associated with getting acceptable material properties when processing mixed plastics.

- To slow down the degradation of plastics, stabilisation additives are employed. Other additives such as fillers or modifiers can be incorporated to improve the properties of the recyclates.

Degradation of plastics:

- Due to their chemical make-up, most plastics damage from the influence of the environment due to the action of light, heat and weathering. So there is drop in both the visual and mechanical properties of the plastic, and it affects both virgin and recycle materials alike.
- Plastics are also damaged from the shear force that can arise during standard manufacturing processes and granulation.
- High temperature accelerates degradation.
- The level of this degradation depends on the polymer type, on thermal and shear stress history and on the initial stabilisation. Additives are commonly added to plastics to inhibit or slow down these reactions.
- In order to measure the stabilisation of a plastic, be it virgin or recycle, information is required on the effects of processing, heat and light.

Stabilities:

1- Processing stability:

- A common method to investigate processing stability is through the repeated cycling of a sample, such as by extrusion or injection moulding. Mechanical tests such as tensile and impact and rheological tests such as MFI (melt flow index) can then be used to see if changes in the properties of the plastic are occurring.

2- Heat stability:

- Temperatures used:
 - 1- The temperature at which the plastic decomposes.

- 2- The maximum temperature at which the plastic can be satisfactorily processed without changes in colour or other problems. These problems would include decomposition of the polymer or other additives employed, for example colourants.
 - 3- Long time heating temperature.
- A combination of heat and oxygen will cause oxidation in the polymer, resulting in degradation. The mechanism is the formation of free radicals, which are highly reactive chemical species. This reaction can be observed, as the products will tend to show a discoloration to yellow or brown. Additives called antioxidants can be used to interrupt this mechanism. The chemicals most commonly employed are hindered phenols, which act as peroxide radical decomposers.

3- Light Stability

- Machines can simulate weathering cycles by control of light (including ultraviolet (UV)) intensity, heat and humidity. Samples can be exposed to detailed, programmed cycles similar to those that components would be exposed to in service.
- Leave samples outside exposed to the natural environment.
- Ultraviolet range can induce photooxidation causing degradation and cleavage of the polymer chains.
- Stability is attained by some stabilizers as benzophenones and benzotriazoles.
- Quenchers contain chromophores (light-absorbing species) which absorb energy and convert it into less harmful forms. Most commercially available quenchers are nickel compounds.

Recycling types:

- 1- Mechanical
- 2- Chemical (for TS especially or further process for TP)
- 3- Thermal (Pyrolysis, Hydrogenation, Gasification)